YBCO High-Rate In-Situ Coated Conductor Process

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Guidelines (by Organizers) for Talks on CC Research at Universities:

- Meet Goals of Long Length with Good Properties
  - **Yes: C/P of ~ \$1/kA·m Feasible in Future**
- Apply to On-Going Effort at National Labs – Discussion
  at Industries – Not at present
- Apply to One Specific Process?
  - **Results Broadly Applicable to Most Processes**
- New Ideas, Directions? – Yes:
  - Generally…
    - High Rate, Large Area, High Ic and Low Cost of Materials Processes Will Eventually be Required – Not Immediately but in 10 Years
    - High Rate May Require Growth in Liquid Flux

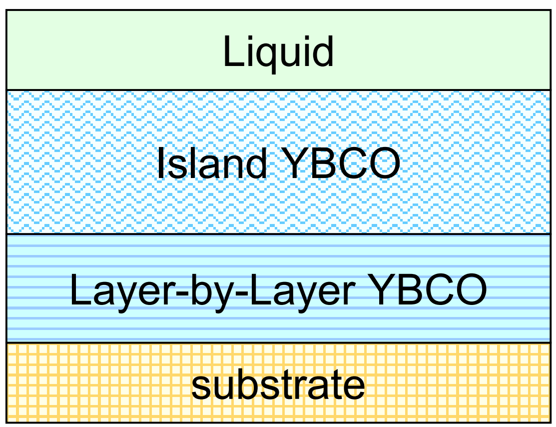
AFOSR-MURI Program on Coated Conductor Program at Stanford

- Scanning Probe Studies - SQUID, Hall, Potential
  - K. Moler & students, M.R. Beasley & students
- Alternate Materials – 248 YBCO
  - T.H. Geballe & G. Koster(Res. Assoc.)
- FTIR – Temperature & Optical Properties
  - G. Koster & M.R. Beasley
- Thickness Dependence of J_c
  - W. Jo(Res. Assoc.) & M.R. Beasley
- Phase Stability, Phase Relationships in YBCO*
  - J.U. Huh(Student) & R. Hammond

*Organizers Requested Talk on This Aspect Related to DOE

Understanding of High-Rate Process

- High Rate Electron-Beam In-Situ Co-Deposition
- Low Pressure Process (5×10^{-5} torr) → Large Area Deposition
  - $C/P = \dfrac{\$}{(Rate)\times(Area)\times Jc} \Rightarrow \sim \$1/K\cdot A\cdot meter$ Possible
- Two Kinds of Growth Morphology + Liquid Flux

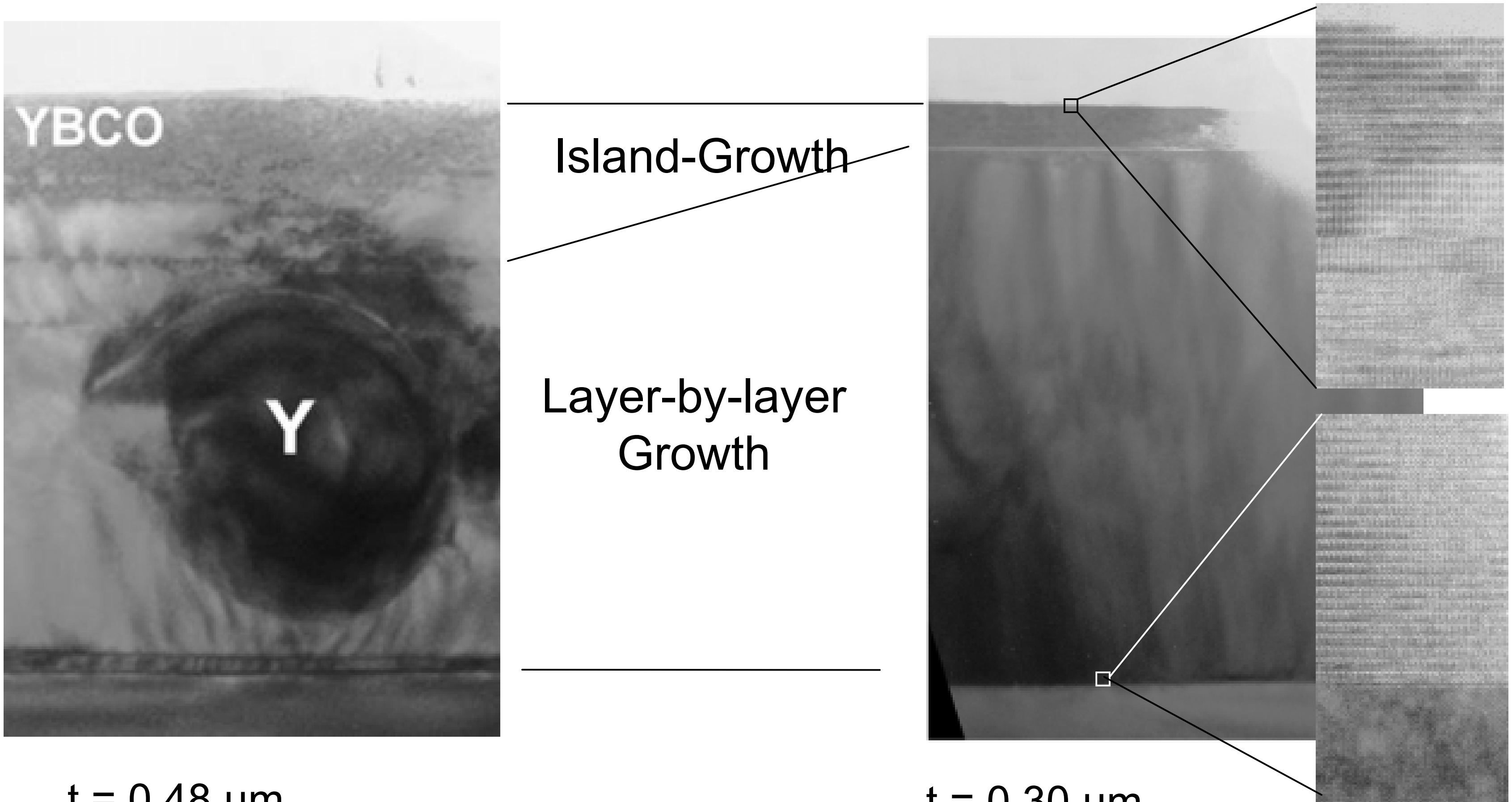


J_c High ~ $5 MA/cm^2$

$J_c = 0$

  - $\mathcal{R}$ = Thickness ratio (Island/Total) $\propto$ Rate of Deposition
- Stability Region for High Jc

Two Types of YBCO



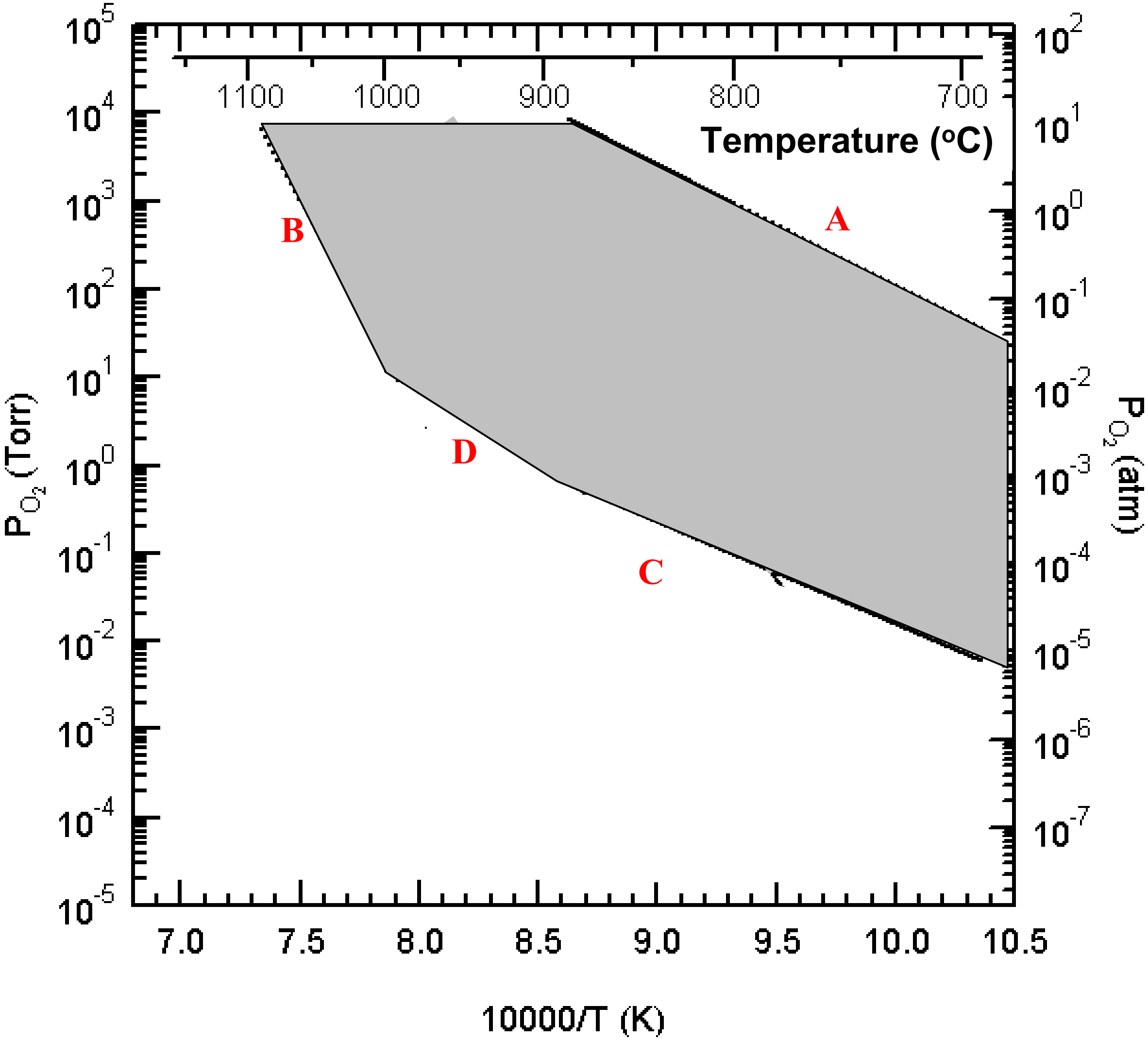
t = 0.48 μm
<Jc> = 0.47 MA/cm^2

t = 0.30 μm
<Jc> = 0.07 MA/cm^2

Thicker faulted layer → Higher <Jc>

YBCO Phase Stability:

Stable Within Boundary A, B, C, D - Lindemer, Driscoll



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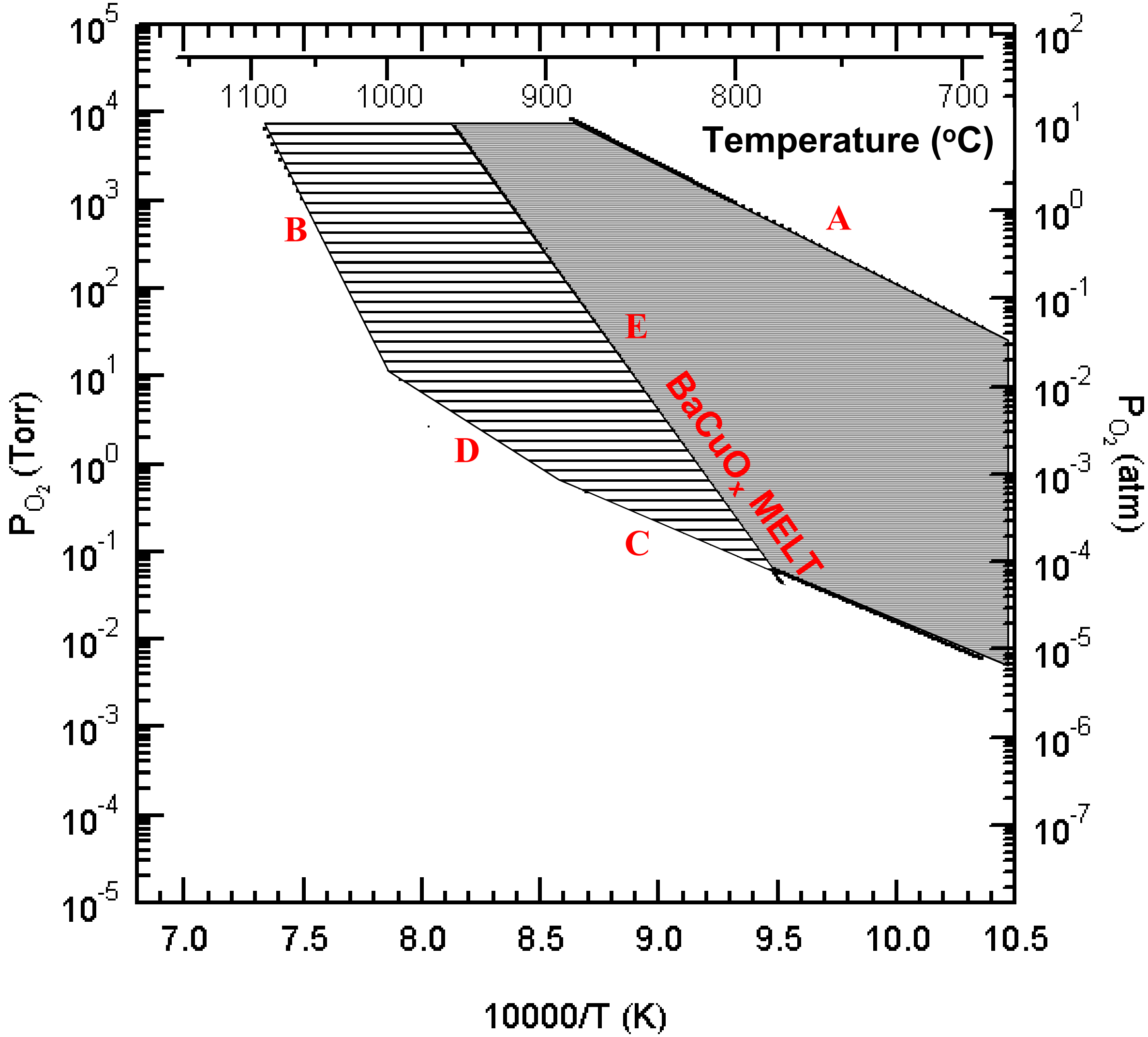
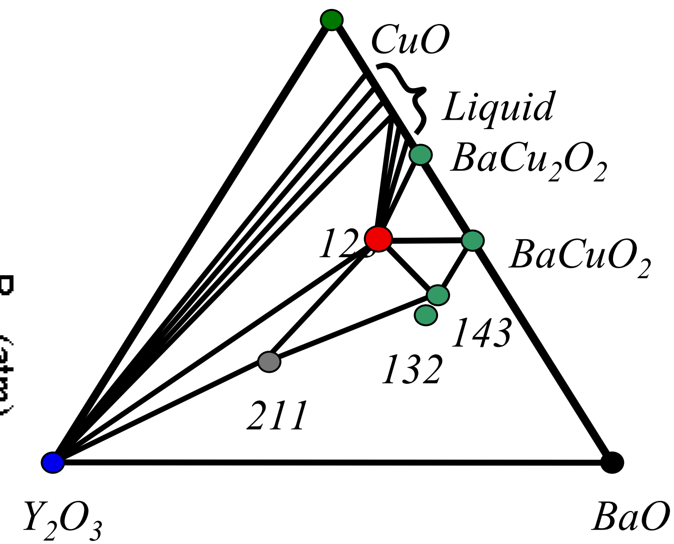
$BaCuO_x$ Liquid to Left of "E" - Driscoll





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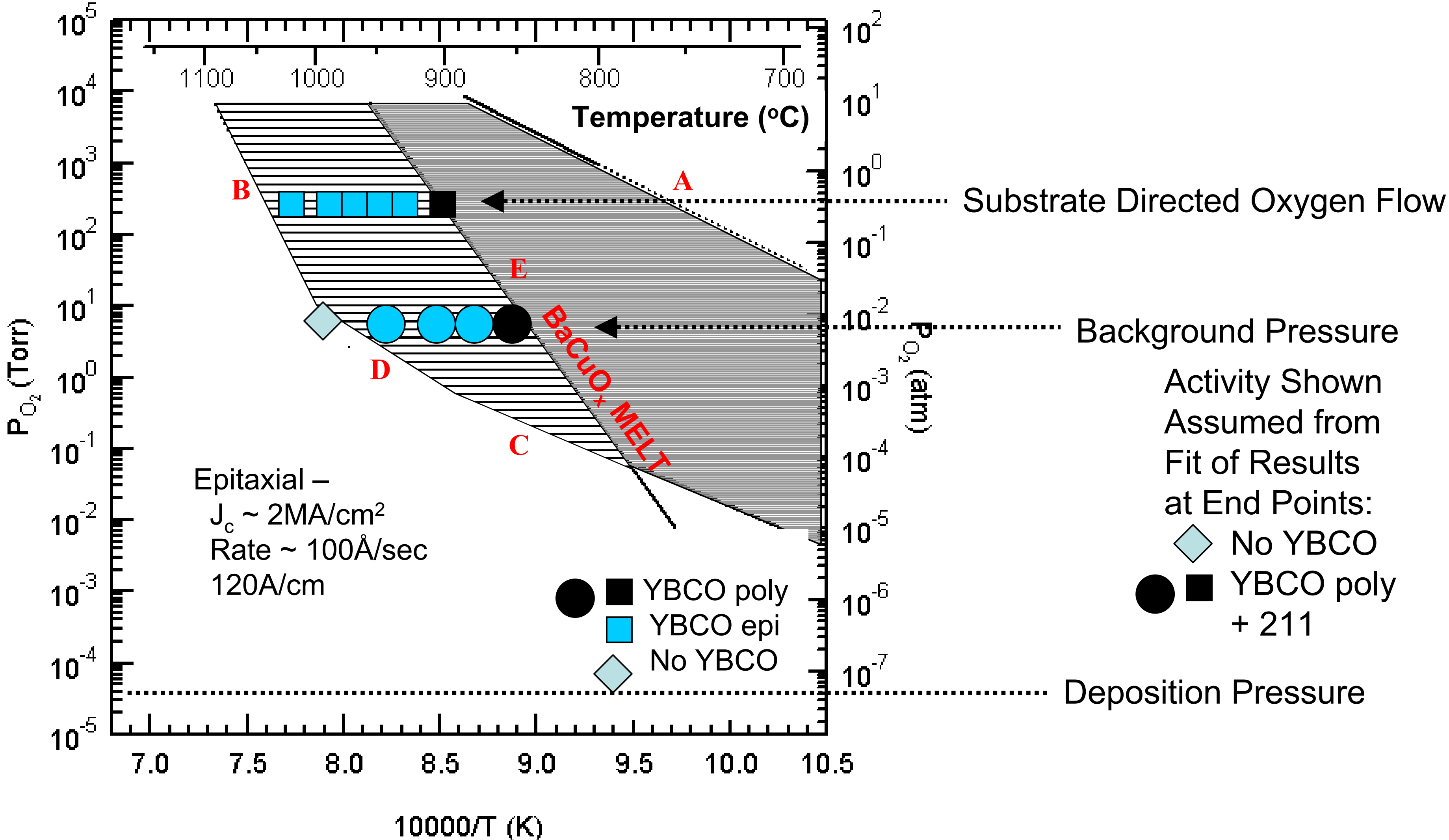
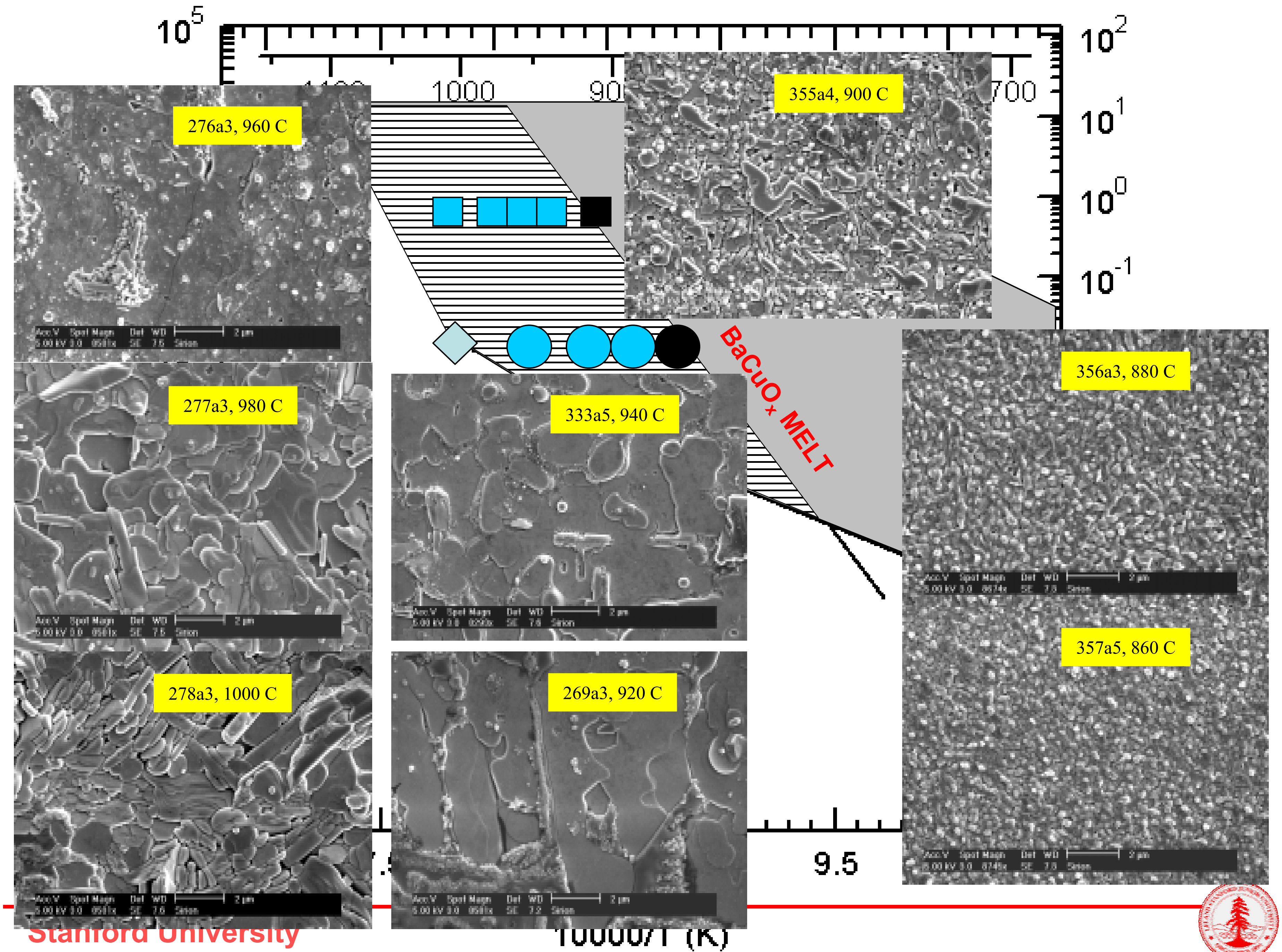


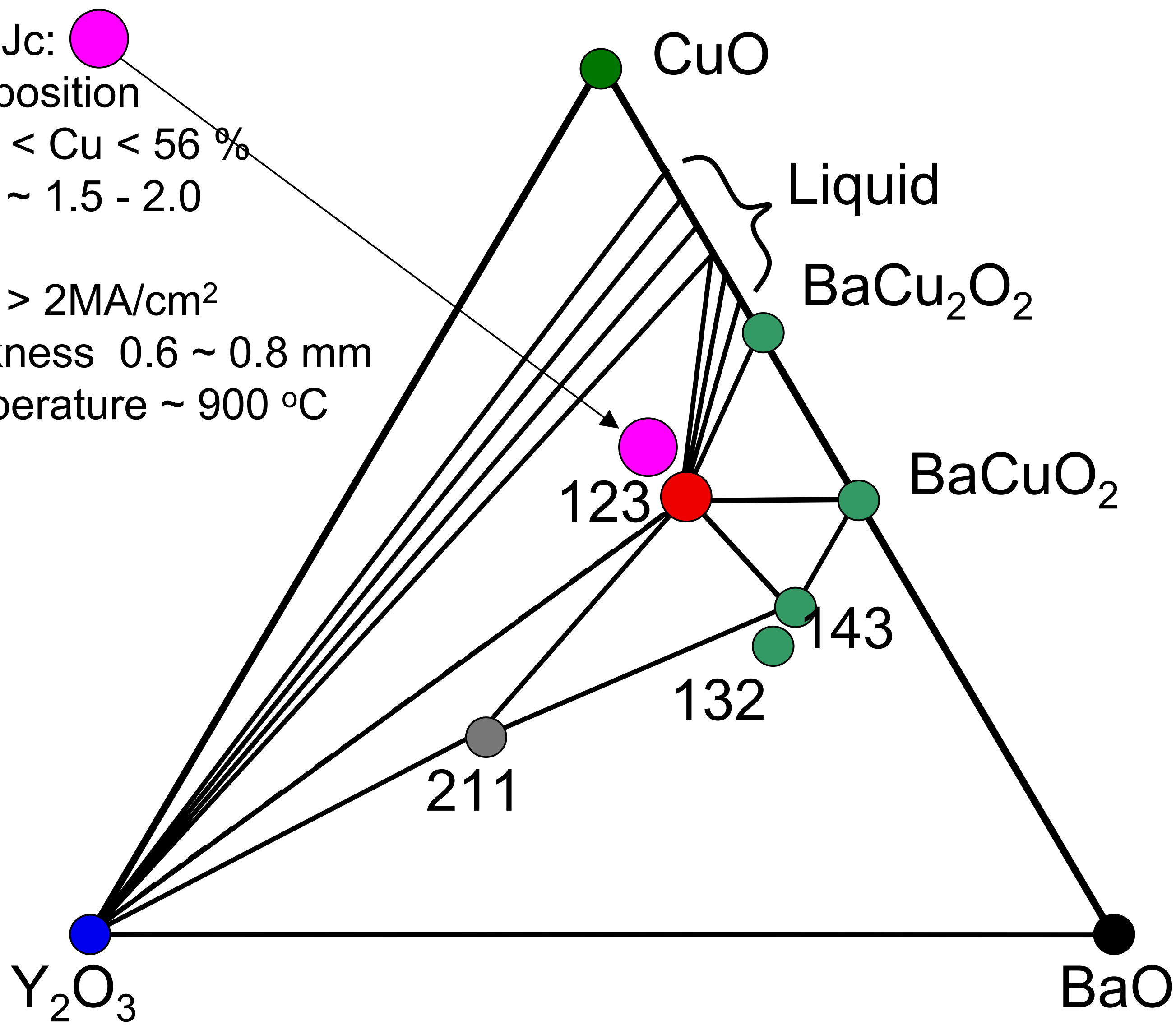


276a3, 960 C
277a3, 980 C
278a3, 1000 C
333a5, 940 C
269a3, 920 C
355a4, 900 C
356a3, 880 C
357a5, 860 C
BaCuO$_x$ MELT
1000
700
9.5
1000/T (K)

At Rate: 100 - 150 Å/sec

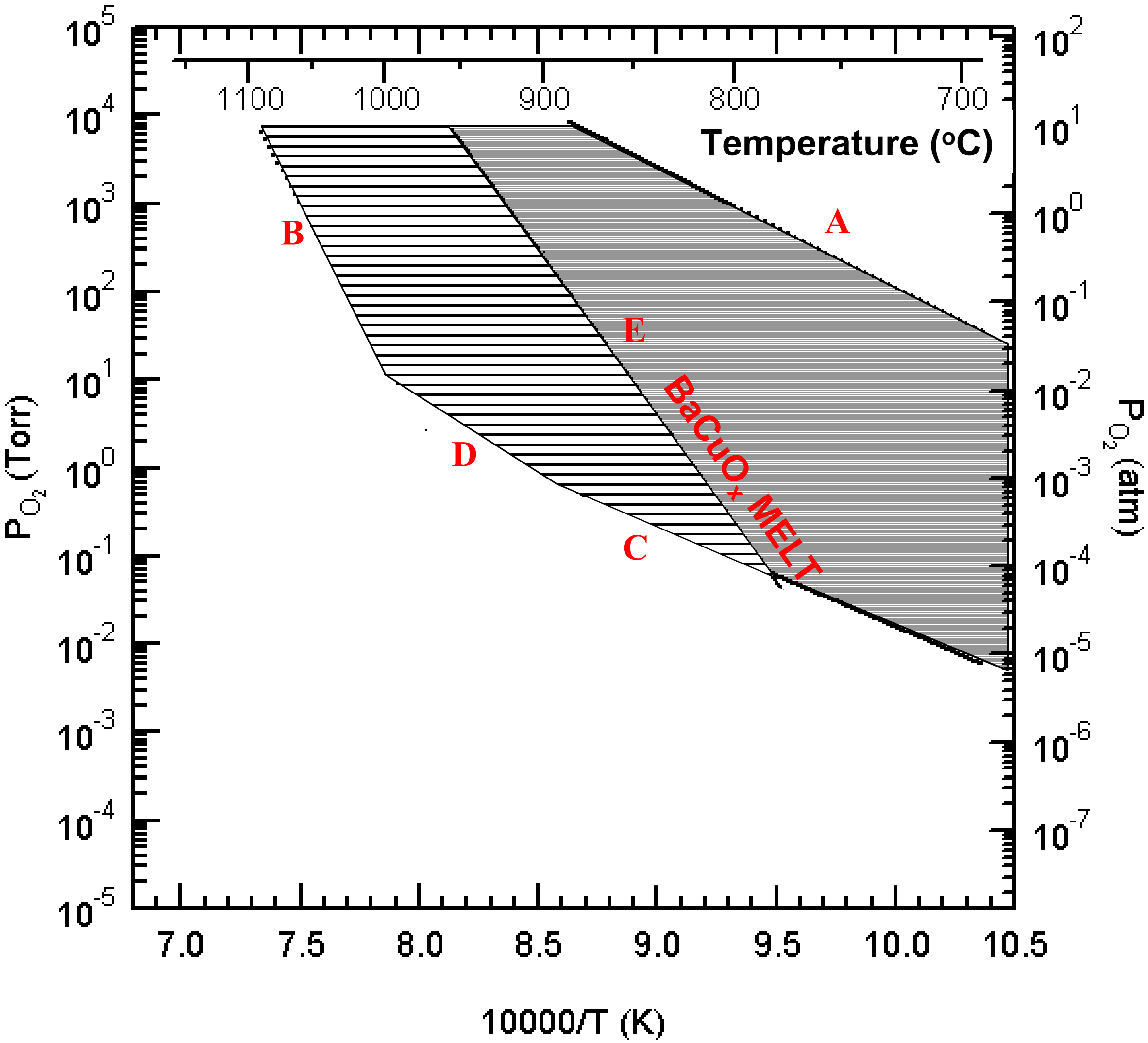
High Jc:
Composition
50 % < Cu < 56 %
Ba/Y ~ 1.5 - 2.0

<Jc> > 2MA/cm^2
Thickness 0.6 ~ 0.8 mm
Temperature ~ 900 ^{o}C



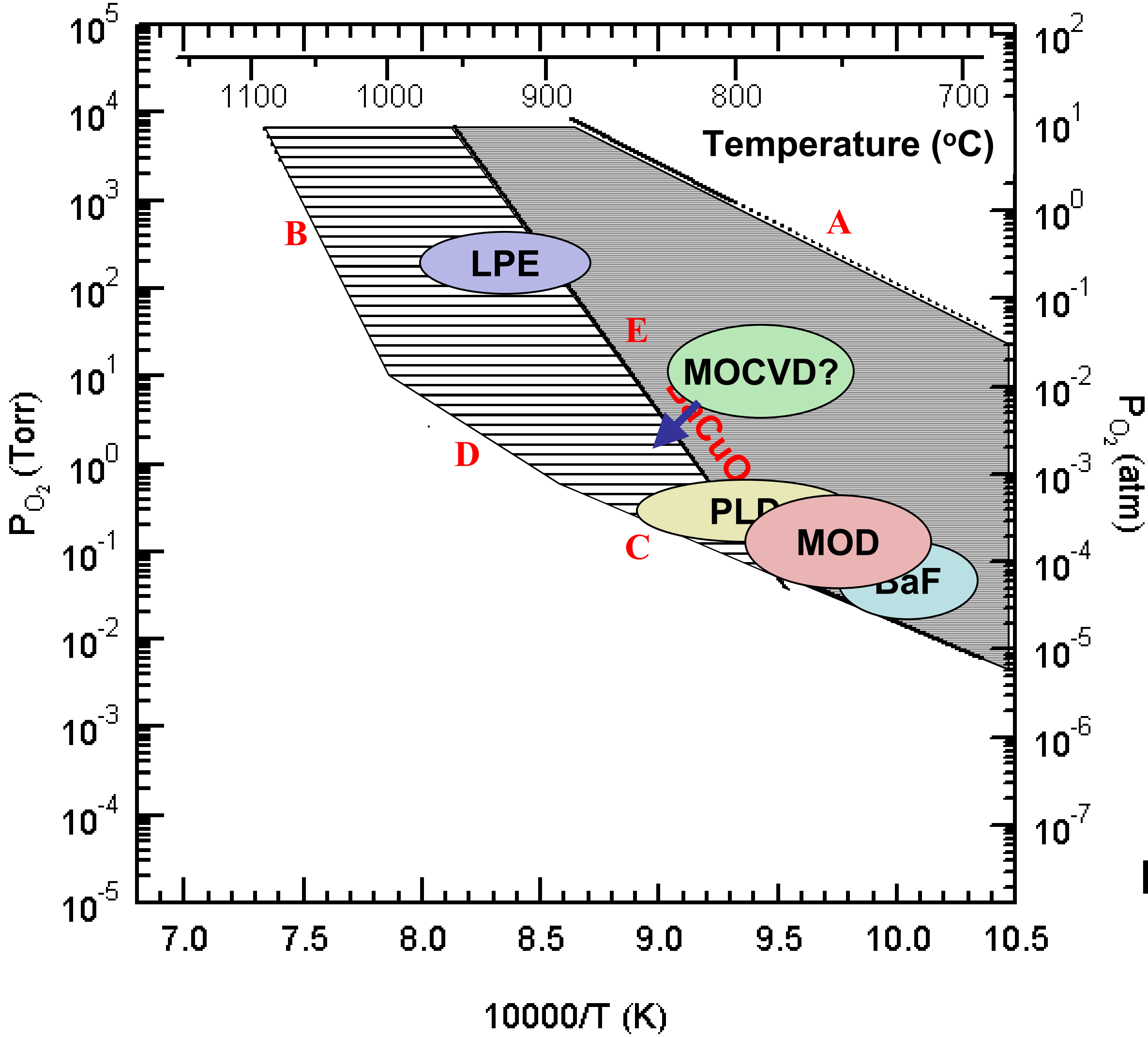
Liquid Flux Melting Point:

Measurement and Lowering?



- Measurement Method
  - FTIR → Reflectivity
    Laser Reflectrometer
- Lower Melting Point
  - F Lower by ~50°C Driscoll
    NIST
  - F-O-OH Lowers more:
    "Liquid" < 700°C, NIST
    Winnie Wong/Larry Cook

Relation to Other YBCO Coated Conductor process:
Effect of Liquid Flux Growth



- Note that MOD and BaF2 processes involve F and H_2O. This will lower the M.P. to < 700°C possibly.

•CCVD could also benefit from liquid flux assisted growth

High-Rate Needs Liquid Flux

A. YBCO Film Growth (Cont.)

Next Issues

— Confirm High Average Jc $\propto$ Rate $\rightarrow$ 350 Å/sec
(Fraction of Growth with High Local Jc)
— Thickness Dependence

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— Metal Tapes - good growth on RABiTS and YSZ-IBAD
- but some reaction
- Lower Temperature
Decrease Oxygen Activity
Lower BaCuO Melt Point - F_2
- Buffer Layers $SrRuO_3$
$CaHfO_3$
Nd_2CuO_4
$LaMnO_3$

— In-situ Measurement
Oxygen Activity - YSZ solid electro-chemical cell
True Temperature - FTIR

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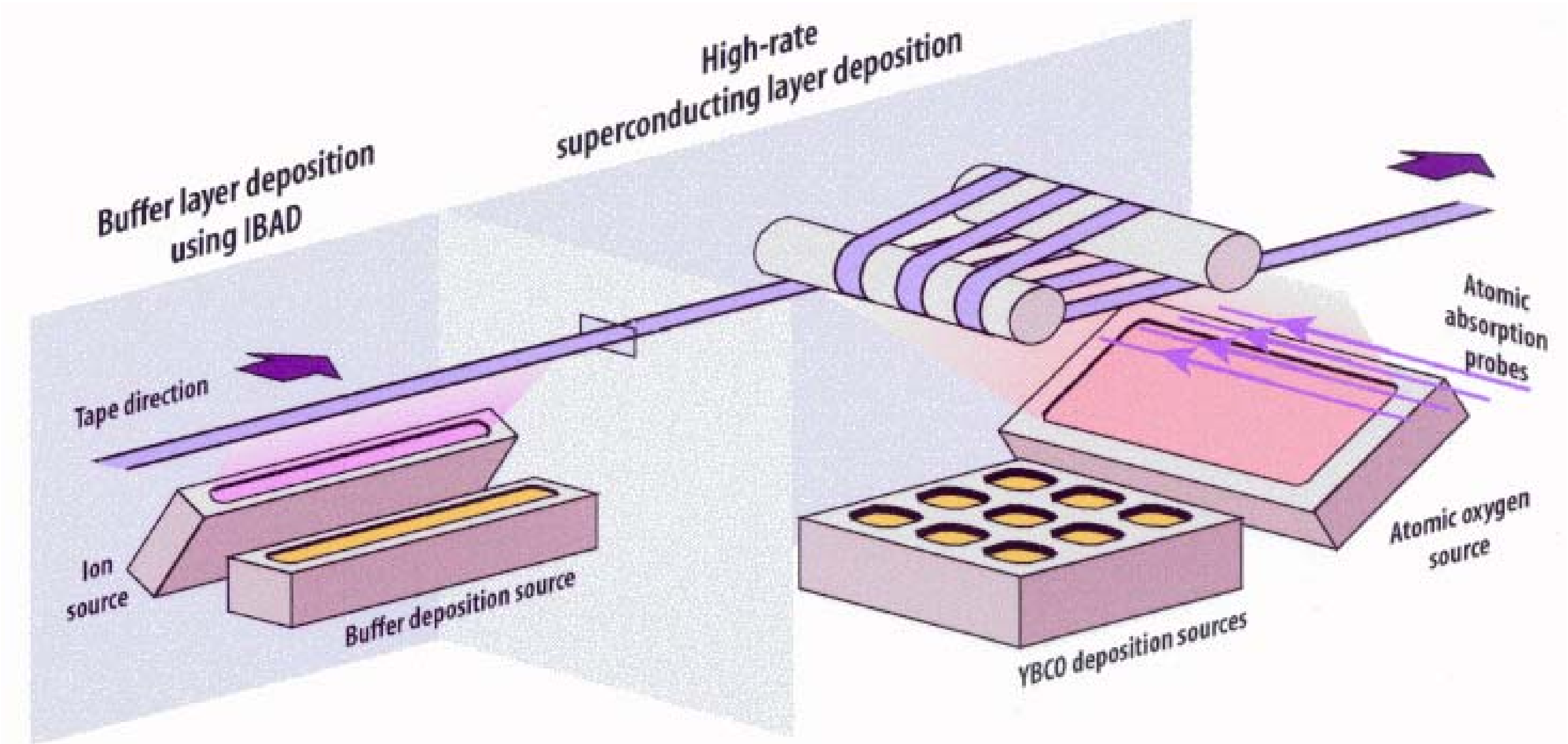
Issues Related to Long Term Scale-Up



ISS' 95

<u>Sensors for Process Control:</u> Stanford has over a decade involvement Through various support and collaboration of process control

AFSOR	— Tunable Diode Laser - Atomic Absorption
DARPA	Physics of Evaporation
3M	— Atomic Oxygen Generation and Sensing
New Focus	
SC Solutions	
Univ. of Michigan	— Modeling of Multiple Element Vapor Flow
Columbia Univ.	
Cal Tech	— Development of RHEED - Cal Tech
Princeton	Courant Inst.
LLNL	LANL
	— Process Control - SC Solutions
	— FTIR - Temperature and Optical Property Sensing

Process Choice Bottom Line:

Cost/Performance Ratio and Total Current

$$\frac{\$ \text{ per Year}}{\text{Yield} \times \text{Ic}}$$

1000 Amp/cm(width) = Jc × Thickness

Thus, $\begin{cases} Jc = 3.3\ MA/cm^2 \\ \text{Thickness - } 3\ \mu m \end{cases}$ for example

$$C/P = \frac{\$/\text{year}}{\text{Rate} \times \text{Area} \times Jc} \ [\$/KA\text{-}m]$$

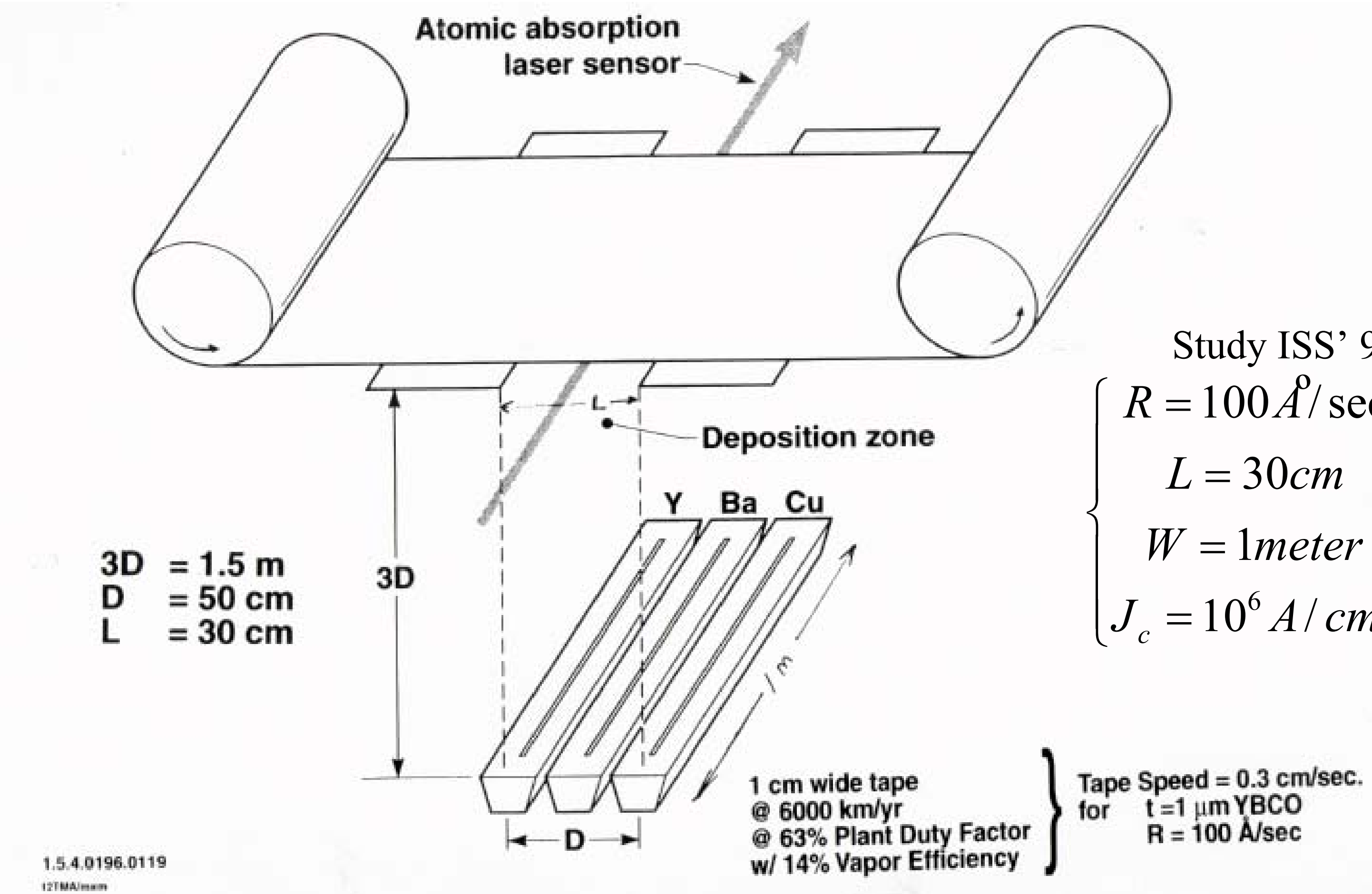
Compare Processes:

- BaF_2 post-annealing
- MOD
- MOCVD
- PLD
- LPE
- in-situ

Proposal:

In-situ's High Rate, Large Area, and High Jc Can Overcome High Capital Cost. Material Cost Lowest

Plant Design for 6000km/year 1cm Wide Tape
Based on LLNL Vapor Flow Modeling



Study ISS' 95:

$$\left\{ \begin{array}{c} R = 100\,\text{Å}/\sec \\ L = 30cm \\ W = 1meter \\ J_c = 10^6\,A/cm^2 \end{array} \right\} \rightarrow$$

C/P = \$10 /kA-m
@ 6000 km/year

Rate = 330Å/sec
Jc = 3.30MA/cm2
C/P = \$1/kA·m

SCALE UP ISSUES: In-Situ High Rate E-Beam

C/P → Lab research in near future:
Rate ↑ (500 ~ 1000 Å/sec), Jc ↑ on Tape

Transfer to Production:
Need Sensor of Oxygen Activity
Composition Control - O.K.
Temperature Control - O.K.

Application — All Metallic Tape
Copper (Alloy) Substrate
Metallic Buffers
Metallic IBAD - New Research Needed

Summary

- Progress in Understanding Phase Stability and Liquid Flux Assisted Growth

- Suggestion that Fraction in High Jc Morphology Improved with High Rate

- <Jc> > 2.5MA/cm^2 at 50% Island Fraction, Local Jc ~ 5MA/cm^2

- Process Temperature Lowering Possible with:
  - Control of Oxygen Activity
  - Addition of F, OH

- Effort to Develop Sensor for in-situ Oxygen Activated Started (Prof. D. H. A. Blank, Univ. Twente)